Launch System Studies and Exploration Transportation System Strategic Roadmap Update

February 8, 2004

Mark Saunders

Presentation Objective

- Describe state of Exploration Transportation Systems Strategic Roadmap (ETSSR)
- Address ETSSR projections of capabilities for Mars roadmap to assume as a function of time (say 10, 20, and 30 years out)
- Identify major gaps and any fundamental paradigm shift to meet future needs (e.g. where does state-of-the-art approach break down and we have to switch to new approach)
- Describe assumptions team has made about future requirements for Mars exploration

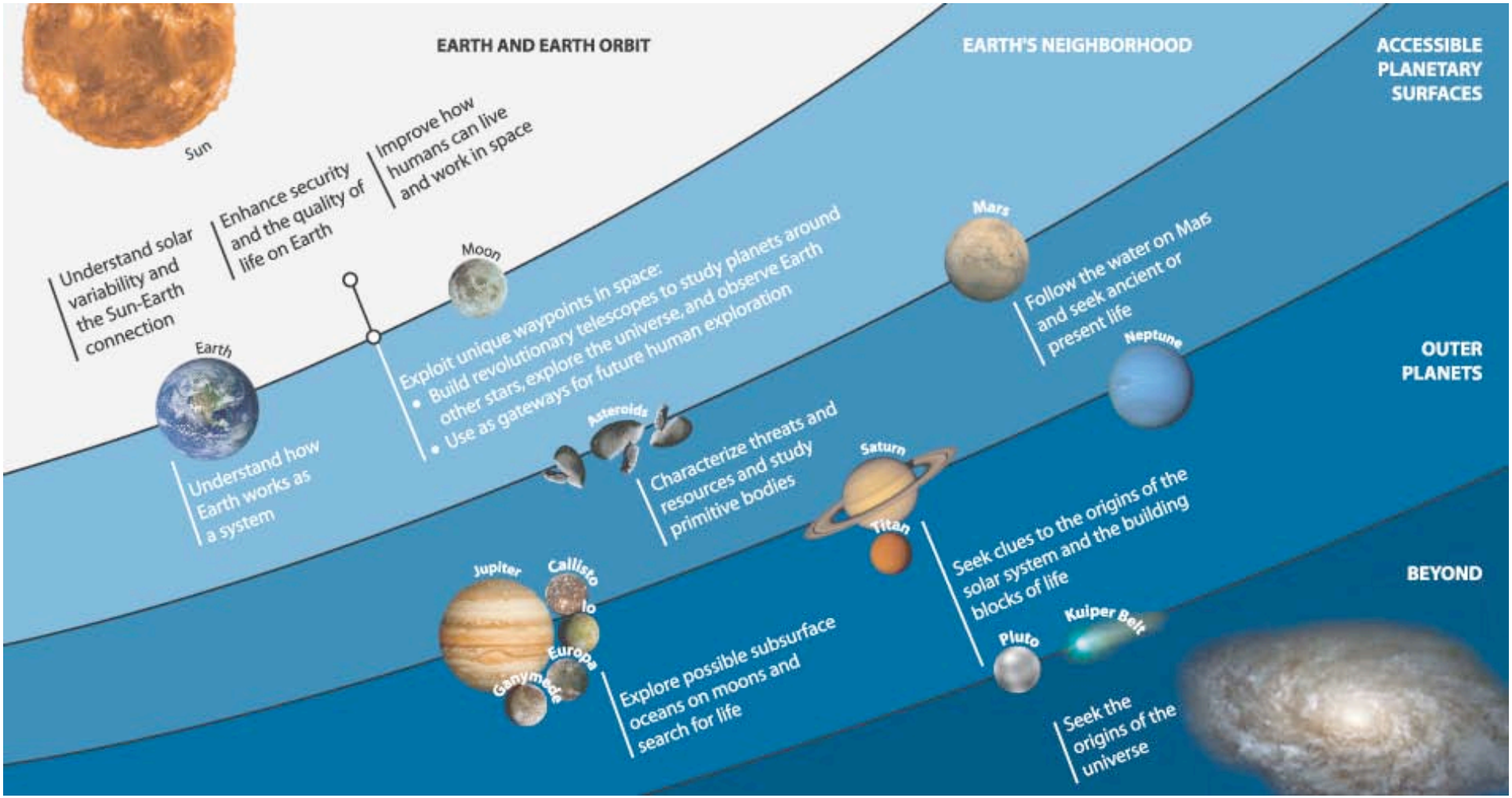
ETSSR First Meeting Goals

- Build consensus on boundaries of Exploration Transportation Roadmap
- Provide introduction to some potential roadmap inputs
- Discuss strategies for developing details of roadmap
- Begin to identify gaps in knowledge or understanding
- Brainstorm to provide inputs for staff analysis and synthesis
- Identify requirements, actions, and desired content for next meeting

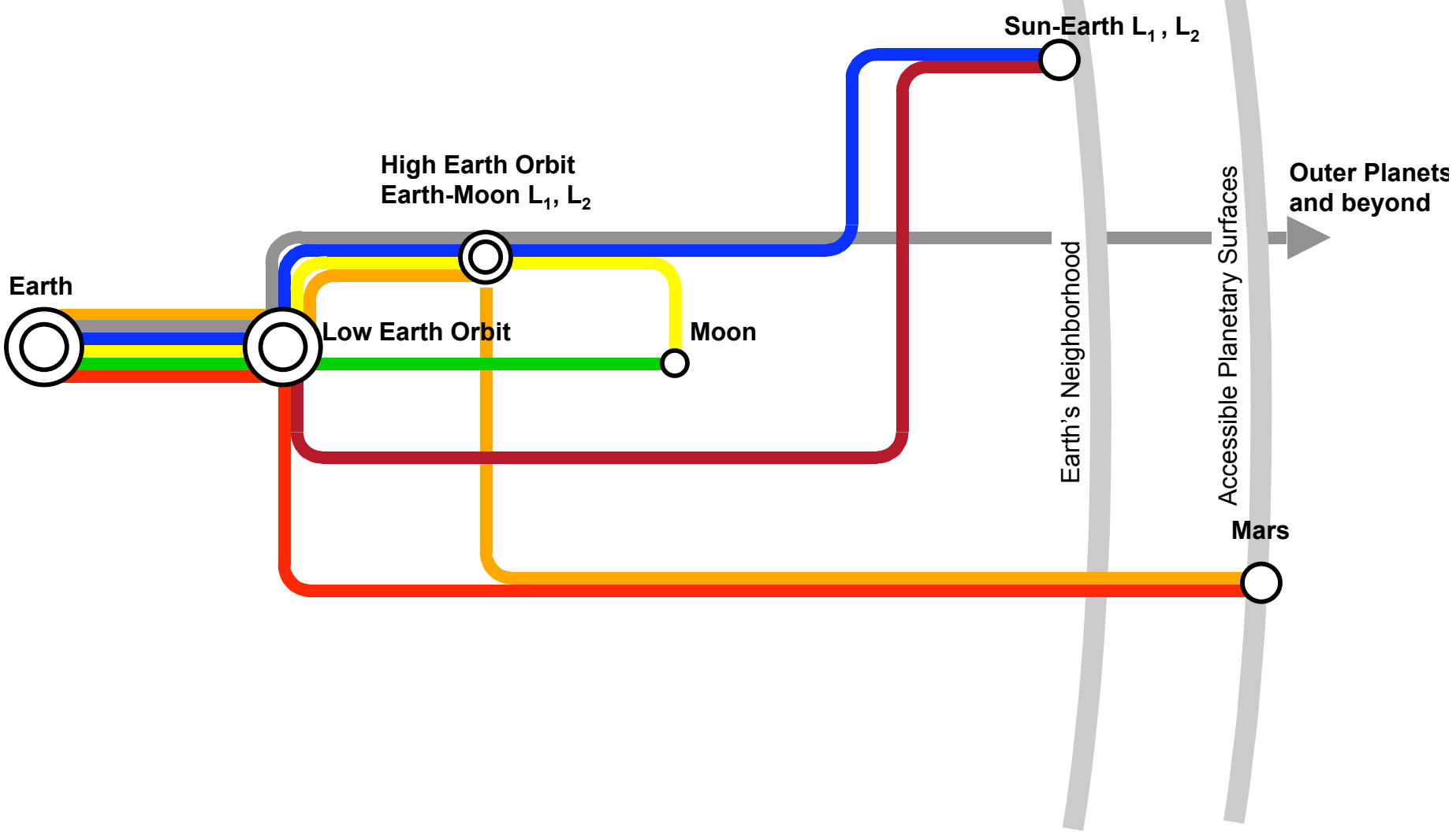
Some Tentative Conclusions…

- Roadmap must be broadly applicable to Exploration (big E), not exploration (little e); Consider transportation needs for all NASA missions
- Roadmap must encourage entrepreneurial endeavors—to increase likelihood of breakthroughs
- Need to understand requirements ***drivers***
- Need to capture risk tolerance as an independent variable within our roadmap
- Need to look at pragmatic partitions
  - Items that ***differentiate*** architectures vs items than ***enhance all*** architectures
  - Items that are answerable in ***near-term*** vs items that are answerable in ***far-term***
  - Hierarchy of questions
- Need planning that provides adaptation when projected technology does not pan out
- Develop a checklist—criteria to help us confirm we've built complete roadmap
- Need to ensure our focus is broad—not just launch vehicle-centric

Potential Range of Space Transportation Missions



Exploration Transportation Routes



Space Transportation Needs Assessment

Spiral 1

Key Transportation Capabilities	Key Transportation Functions																				
	Earth To Orbit			Earth Orbital			Earth to Moon			Moon to Earth Return			Earth to Mars			Mars to Earth Return			Solar System
	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic
Transportation Elements																			
ELV / EELV	X	O																	
EELV Derived	O	O																	
Shuttle Derived	O	O																	
Crew Exploration Vehicle		X			X														
Launch Escape System		X																	
Upper Stage / Transfer Stage				X	X		X			X			X						X
In-Space Propellant / Supply Depot																			
Planetary Capture / Entry							X						X						X
Planetary Landing							X						X						X
Surface Mobility							O			O			X			O			
Planetary Ascent										X						X			X
Reentry at Earth				X	X					X						X			X
Propulsion Systems																			
Chemical																			
Liquid																			
Cryogenics	X	X		O	O		O			O			O			O			O
Storables	X			X	X		O			O			O			O			O
Solid / Hybrid	X	O					O			O			O			O			O
Launch Assist	O	O																	
Nuclear Thermal																			
Electric																			
Low Power (<50kw)				O			O			O			O			O			X
Medium Power (50-500kw)							O			O			O			O			
High Power (>500kw)																			
Propellantless																			
Aeroassist (Capture / Entry)				O	X					O			O			O			O
Sails																			O
Tethers																			
Vehicle Systems																			
Lightweight Structures	O	O		O			O			X			X			X			X
Deployable Systems				O			O			X			X			X			X
Radiation Hardening / Shielding					O		O			O			O			O			O
MMOD Protection					O														
Efficient Thermal Systems							O			O			O			O			O
Avionics/Intelligent System Health Management	X	X		X	X		X			X			X			X			X
Power (generation, conversion, distribution)	X	X		X	X		X			X			X			X			X
Communications and Data Handling	X	X		X	X		X			X			X			X			X
Guidance, Navigation & Control	X	X		X	X		X			X			X			X			X
Reaction Control/Orbital Maneuvering	X	X		X	X		X			X			X			X			X
Cryo Fluid Management				O	O		O			O			O			O			
Systems Engineering and Integration (inc. M&S)	X	X		X	X		X			X			X			X			X
Human Systems																			
Life Support		X			X														
Radiation Protection																			
Biomedical Countermeasures																			
Crew Systems: In-space		X			X														
Crew Systems: Surface																			
Artifical Gravity																			
Operations																			
Automated																			
Rendezvous and Docking				X	O		O			O			O			O			O
Manuevering				X	O		X			X			X			X			X
Decision Making				O			O			O			O			O			X
On-Orbit Assembly and/or Repair (EVA)					O														
Launch and Payload Processing / Range	X	X																	
Recovery				O	X					X						X			X
ISRU Propellants/Fluids																			
Propellant Transfer																			
Communications and Navigation Network	X	X		X	X		X			X			X			X			X

Example

X - Probable Need | O - Potential Need | Difference | Not Applicable

Theme Area Development

Mapping to Capability Matrix

Key Transportation Capabilities	Key Transportation Functions																				
	Earth To Orbit			Earth Orbital			Earth to Moon			Moon to Earth Return			Earth to Mars			Mars to Earth Return			Solar System
Transportation Elements	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic	Human	Cargo	Robotic
ELV / EELV	X	O																	
EELV Derived	O	O																	
Shuttle Derived	O	O																	
Crew Exploration Vehicle		X			X														
Launch Escape System		X																	
Upper Stage / Transfer Stage				X	X					X			X			X			
In-Space Propellant / Supply Depot																			
Planetary Capture / Entry																			

Themes:

- **Earth to Orbit**
- ***Transfer To/From* & Orbital Operations**
- **Descent / Surface Operations / Ascent**
- **Earth Capture / Entry**
- **Crew Support**
- **Vehicle Systems**
- **Operations**

X = Probable Need | O = Potential Need | Difference | Not Applicable

Theme: Earth to Orbit

- Current ELV's
  - Are likely to be able to satisfy all robotic and some cargo missions across all Spirals
  - May satisfy Spiral 1 with modifications for human rating
- Shuttle hardware/systems may possibly be utilized in multiple applications
- Commercial capability may be able to satisfy some lift requirements (e.g., propellant)
- Spiral 1 may require a new upper stage for CEV launch
  - May initially use current engine designs
  - May also have applicability (e.g., cargo, in-space transfer) in later Spirals
- Spirals 2 and 3 may require enhanced launch capability, unless a significant orbital assembly capability is developed
- Spiral 4 will likely require significantly greater Initial Mass to Low Earth Orbit (IMLEO) than Spiral 1, 2 or 3
  - This could be satisfied by heavier lift vehicles, propellant depots, more efficient launch/on-orbit assembly capability, etc.

Earth to Orbit Roadmap

- Program Milestone
- Downselect Decision
- IOC Milestone
- Concept / Focused Technology
- Development / Production
- Operations / Support

05 10 15 20 25 30

CEV-FAST | Un-Crewed CEV | Crew CEV | Lunar | Mars

Robotic

Lunar / Mars Robotics

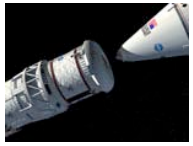
Crew

- Do we use different vehicles for cargo vs. crew? Mixed fleet?
- Do we use Shuttle or EELV-derived? Clean Sheet?
- Role for commercial?

EELV Derived / Shuttle Derived → Crewed LV

Upper Stage Synergy

EELV Derived / Shuttle Derived / Clean Sheet → Crewed LV



Cargo

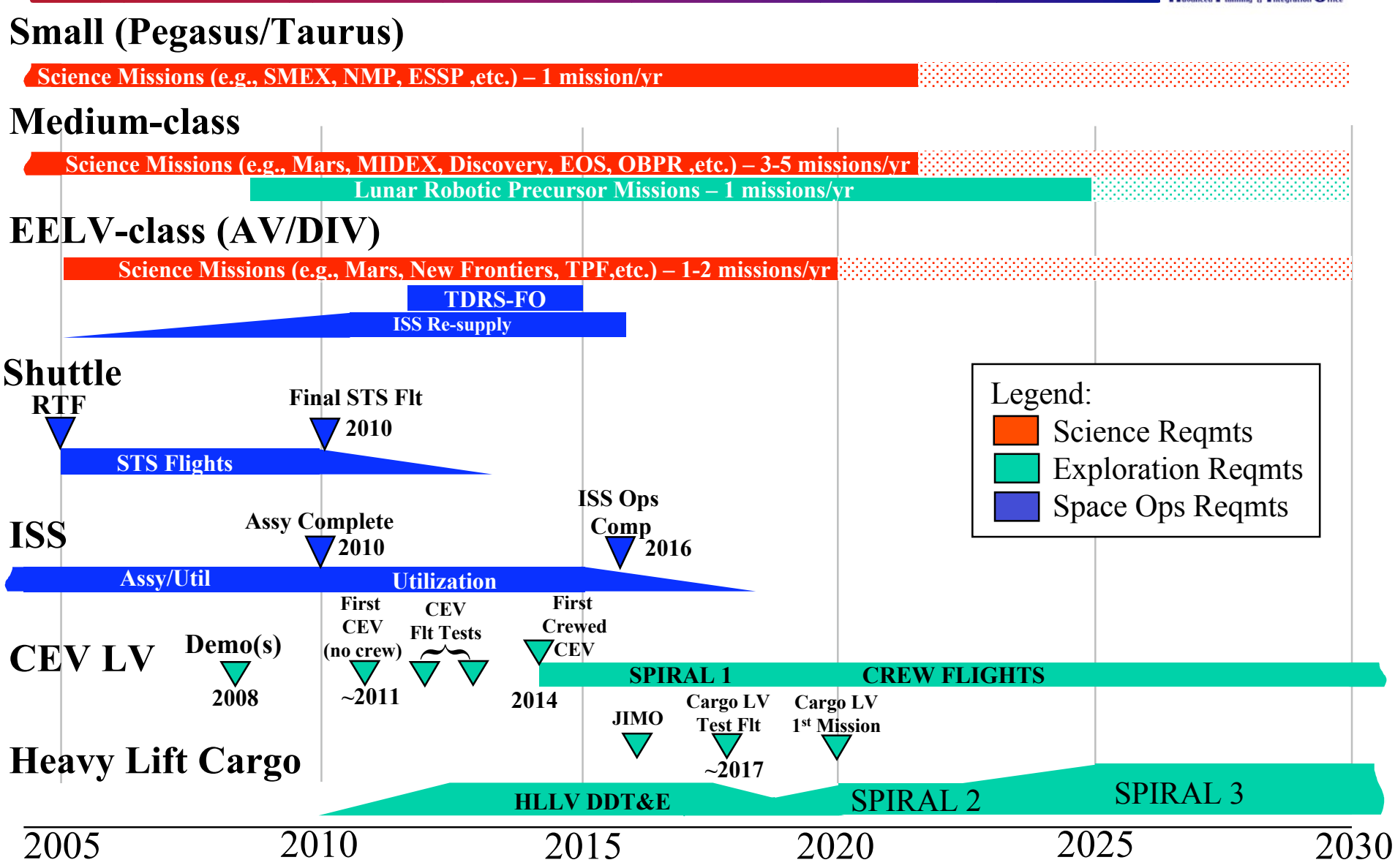
- Degree and timing of heavy-lift needs?
- Do we use Shuttle or EELV-derived? Clean Sheet?
- Do we want to build/modify a vehicle that can also meet Mars heavy lift needs?
- Role for commercial?

EELV Derived / Shuttle Derived → Lunar Cargo LV

Earth Departure Stage Synergy

EELV Derived / Shuttle Derived / Clean Sheet → Mars Cargo LV

Timing of Future Launch Requirements

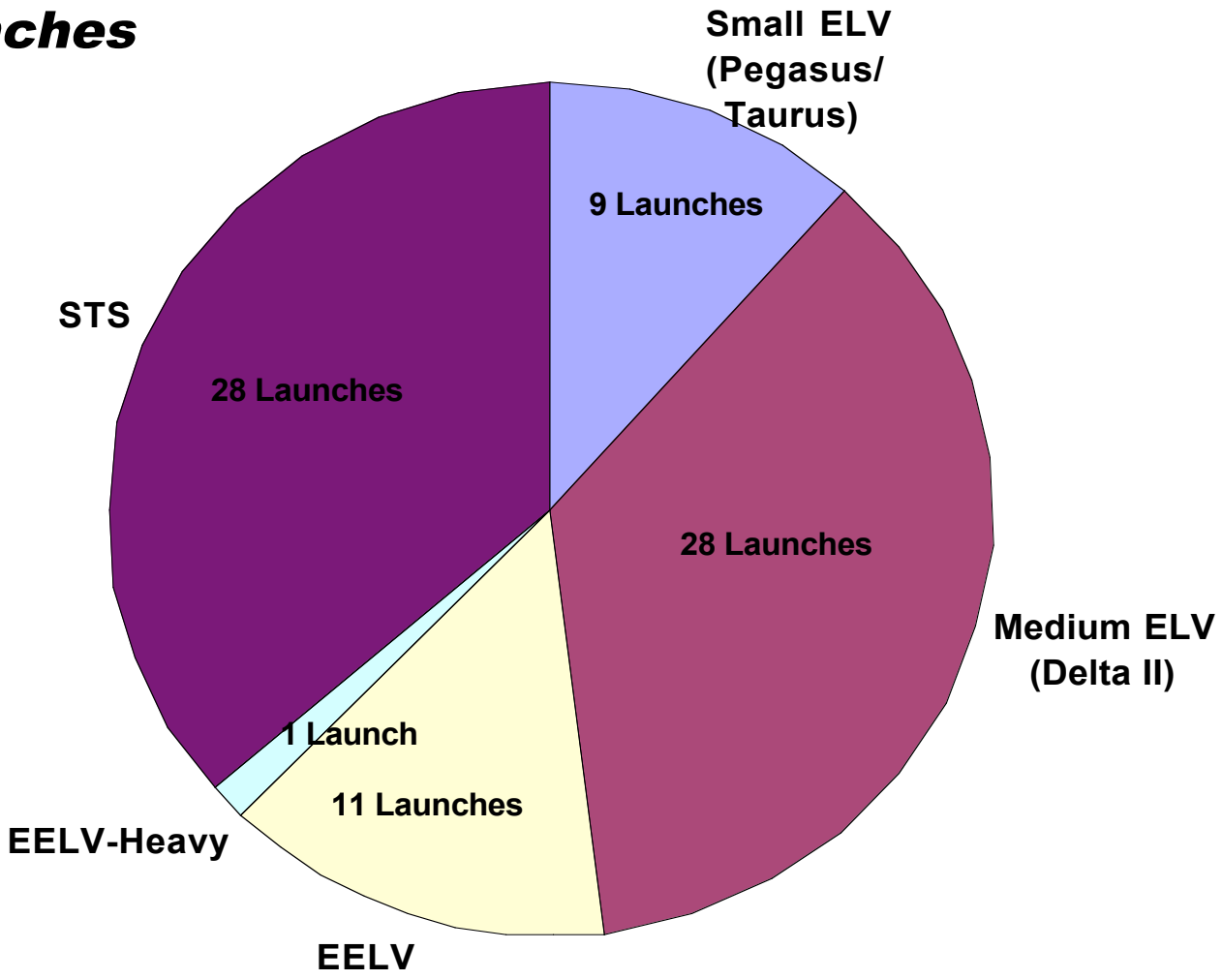


Mixed Fleet

- Accomplishment of Space Exploration Vision and NASA mission has an inherent dependence on safe, reliable, cost effective, on time space access
- NASA employs a Mixed Fleet Launch Strategy to diversify space access across all available commercial launch systems as a lessons learned from Challenger and revalidated post Columbia
- Customers seek to take advantage of full range of space access:
  - OSO provides Shuttle and US ELV's and ISS
  - Sounding rockets, balloons, drop flights managed by Science Directorate
  - International cooperative launches, partner contributed services to ISS, potentially to Space Exploration
  - Emerging launch capability
- Challenge is balancing the requirements of diverse customer base with reality of stagnant external market conditions

NASA Launch Forecast 2005 Budget

77 Launches

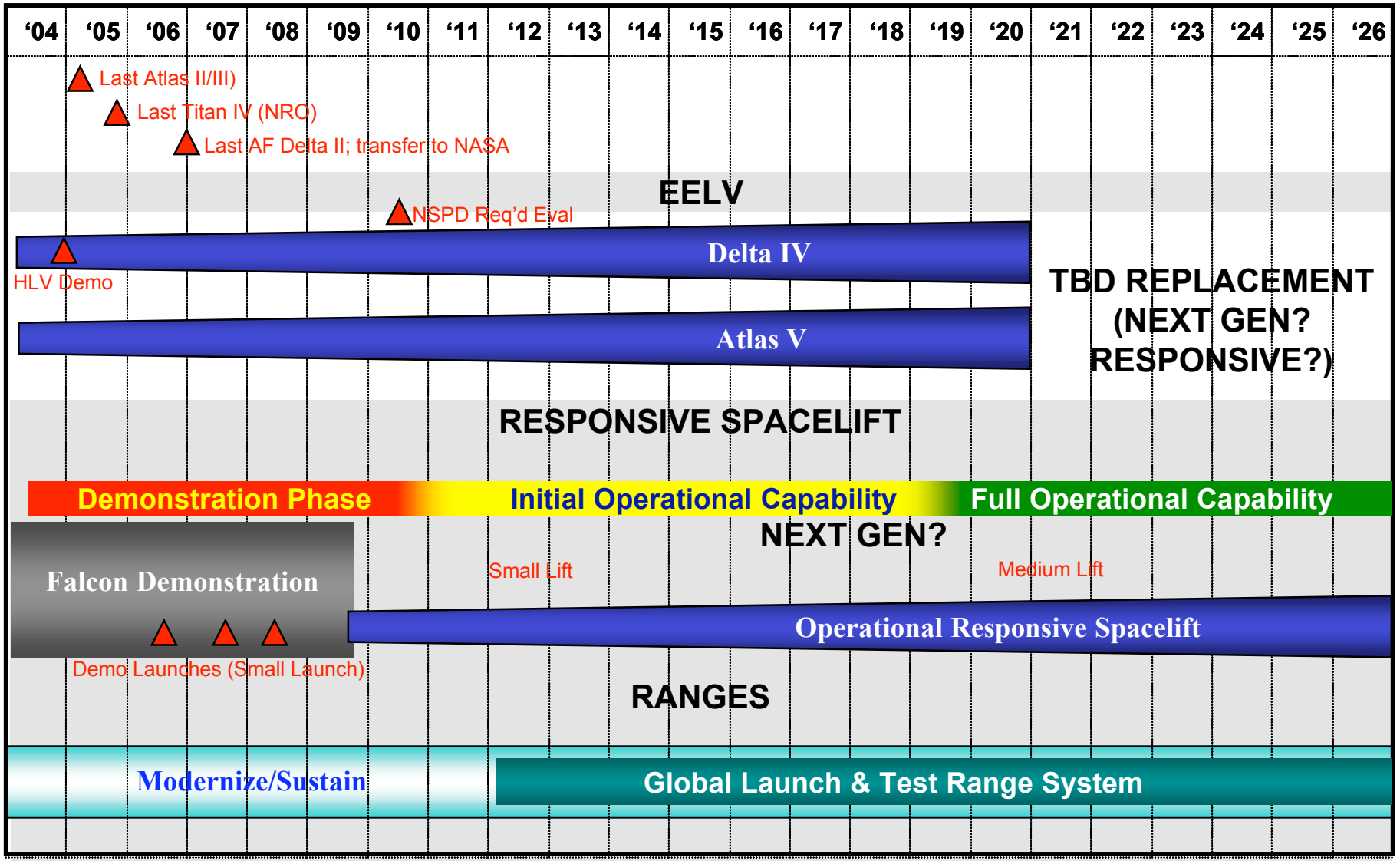


*** Assumes Shuttle retirement in 2010, no replacement missions added**

Commercial Space Transportation RFI

- **RFI identified six categories of future NASA space transportation services requirements**
  - Ground to Low-Earth Orbit Deploy
  - Ground to Interplanetary Trajectory Insertion
  - Ground to Low-Earth Orbit Rendezvous (ISS)
  - Ground to Staging Location
  - Human Transportation and Return
  - In-Space Operations (Transportation Service Node)
- **Received 26 responses**
  - 20 responders addressed some or all six categories
  - Mix of heritage and emerging space entities
  - Offering both domestic and foreign launch options
- **Summary Observations**
  - Appears to be limited opportunity to procure pure commercial-like transportation services beyond free-flyers
    - NASA is sole customer for other uses at this time
  - NASA should be prepared to fund DDT&E costs for any new launch system
    - Current vehicle contractors all have recent bad experience
  - A few emerging launch companies continue to seek to offer commercial services

DoD Space Transportation Roadmap



Recent Studies (SOMD)

Agency Space Transportation Studies	HQ/POC	Center POC	Vehicle Type		
			SDV	ELV	CS
❖Exploration Systems					
Previous Space Transportation Studies	C. Cornelius	P. Sumrall	x	x	x
Exploration Heavy Lift ETO Study - STS-Der'd & Clean Sheet (MSFC)	G. Lyles	S. Cook	x		x
Human Rated Launch Vehicle Requirements	S. Chandler	G. Langford	n/a	n/a	n/a
KSC Infrastructure Study	W. Wiley	R. Eastman	x		x
Integrated Launch System Definition Study (capabilities)	C. Guidi	S Richards	x	x	x
Cargo					
Crew					
EELV - Crew and Cargo					
Crew and Cargo Synergy					
Upper Stage/TLI					
Commercial Businesss Case Analysis					
❖Space Operations					
OSP/ELV Feasibility Studies	K. Poniatowski	D. Foster		x	
EELV Reliability Enhancements (for EELV-OSP system)	K. Poniatowski	D. Foster		x	
EELV Pad Studies	K. Poniatowski	G. Skrobot		x	
EELV Enhancements (JIMO rqmts)	K. Poniatowski	M. Littlefield		x	
Alternate Access to Station				x	
ELV/OSP Human Flight Safety (for EELV-OSP System)	K. Poniatowski	D. Foster		x	
EELV Heavy Lift (Code T Rqmts, Tasking to Boeing and LM) *	K. Poniatowski	R. Mueller		x	
Commercial Access to Space (RFI)	K. Poniatowski			x	
STS-Derived Study (Code T Rqmts) *	R. Lightfoot	M. Henderson	x		
ISS Mixed Fleet Transportation (Comm, IP, SDV, Explor vehicles)	K. Poniatowski		x	x	x
❖Space Architect					
JIMO ETO Options Study	M. Gates	P. Wallace	x	x	
Cost Issue Study for Expendable and Reusable ETO Transportation Options	M. Gates	S. Creech	x	x	x
Transportation Architecture Concepts for a Highly Reusable Architecture	M. Gates	B. Ward			
Parametric Sensitivity Analysis of Transportation Impacts to Mars Architectures	M. Gates	A. Gamble	x	x	x
Sensitivity Analysis of Architecture Modularity and AR&D System Reliability Impacts to ETO Transportation Systems	M. Gates	R. Lepsch	x	x	x
Integrated Space Transportation Plan Analysis	M. Gates	A. Gamble	x	x	x
❖Science					
JIMO Automated Rendezvous and Docking	K. Poniatowski	M. Littlefield		x	
HST Robotic Servicing (Aerospace AOA)	M. Schaffer	V. Hwa		x	

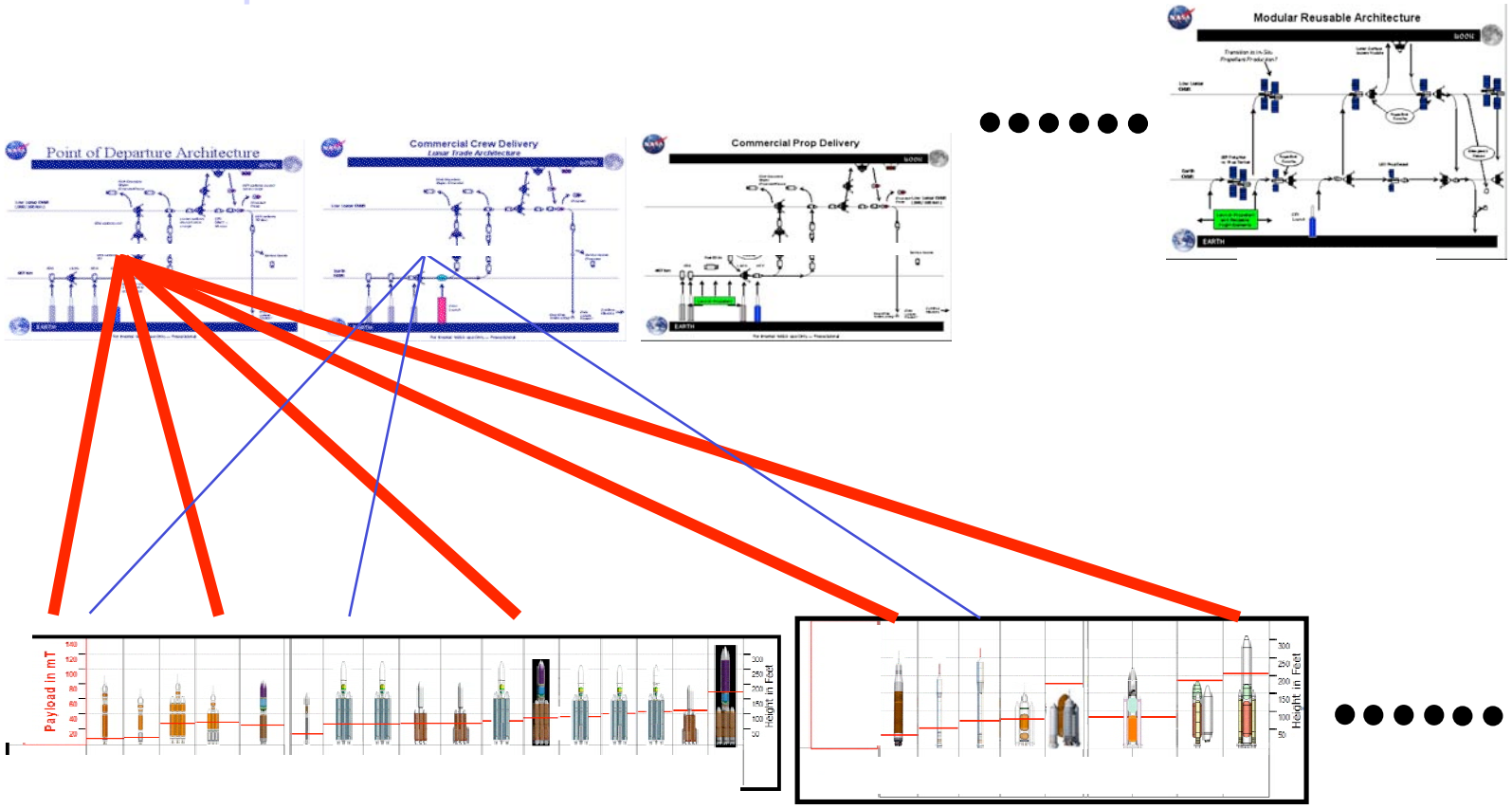
* Space Operations performed as part of Exporation tasks

Launch Systems Study Status

- Recently completed several in-house studies related to launch systems:
  - EELV Heavy Lift Cargo Assessment
  - Integrated Launch Systems Study
    - Crew launch options (analyzed 12 systems)
    - Cargo launch options (analyzed 35 systems)
    - Upperstage / Earth Departure Stage commonality (3 classes)
    - Crew / Cargo Launch Vehicle Synergy
  - KSC Launch Infrastructure Assessment
    - Analyzed the ground infrastructure requirements to support exploration missions
- Concept Exploration & Refinement (CE&R) BAA contractors will include launch needs as a part of their assessments

Approach

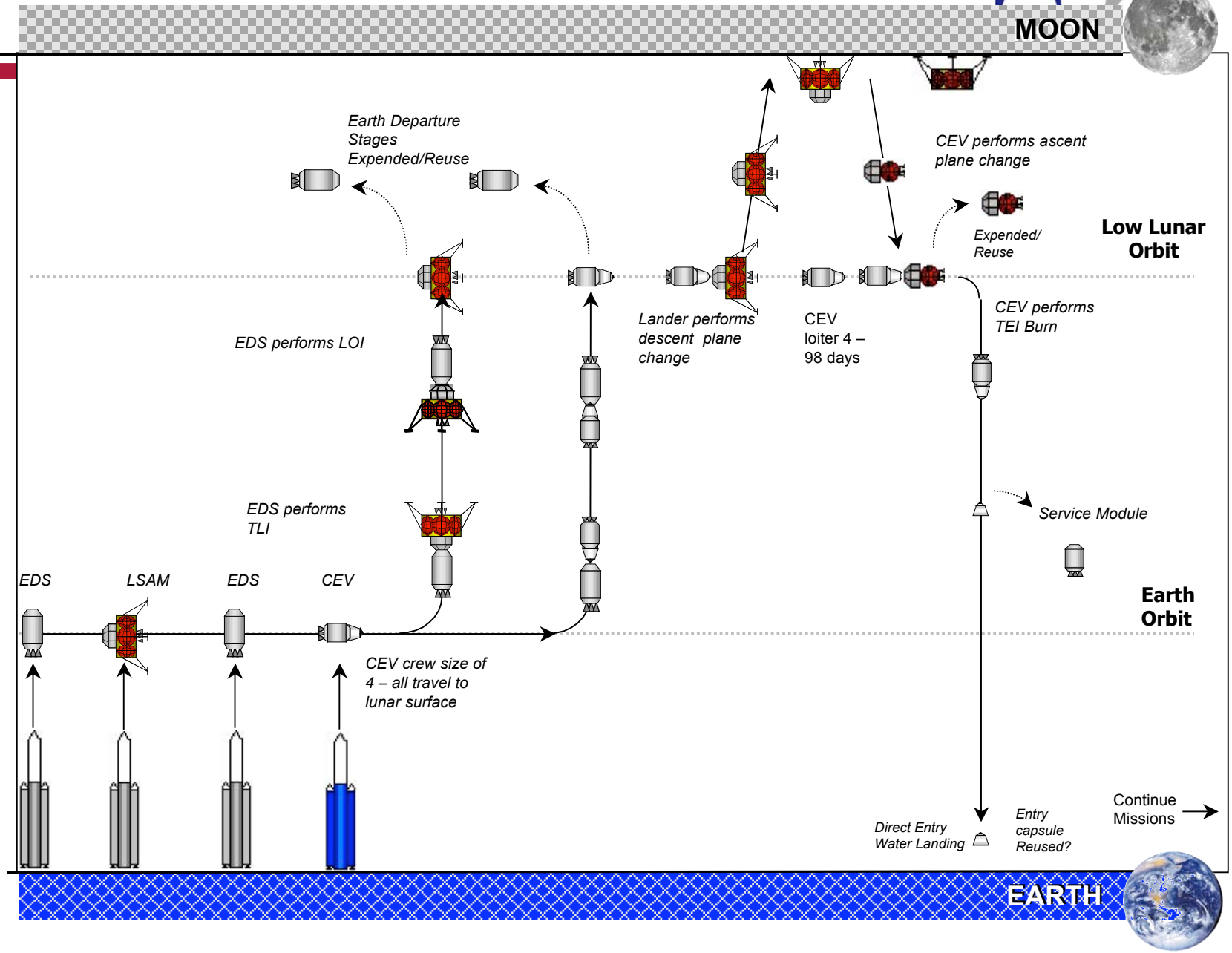
Mission Architecture Options



Launch Vehicle Options

Multiple mission architectures assessed against multiple LV options

POD- Lunar Trade Architecture

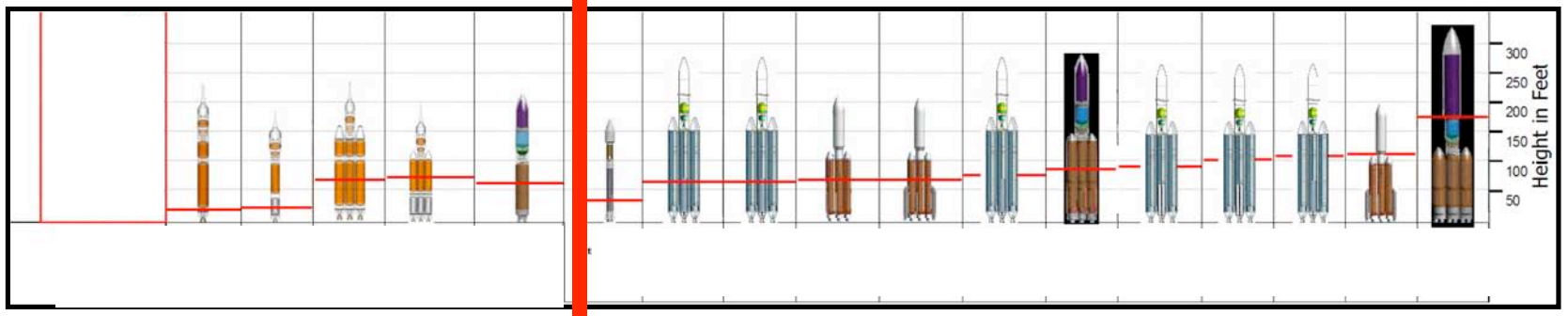


In-House Launch System Study Alternatives Completed

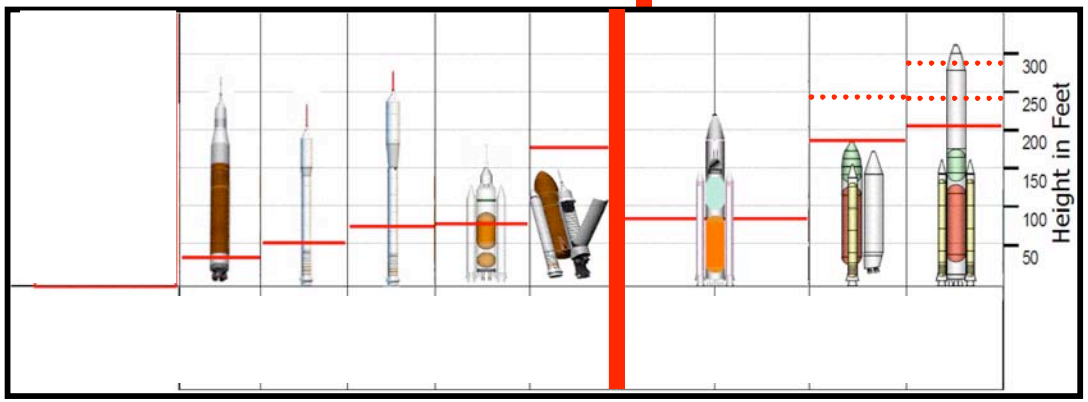
Crew Launch Systems | Cargo Launch Systems

Advanced Planning & Integration Office

EELV Derived

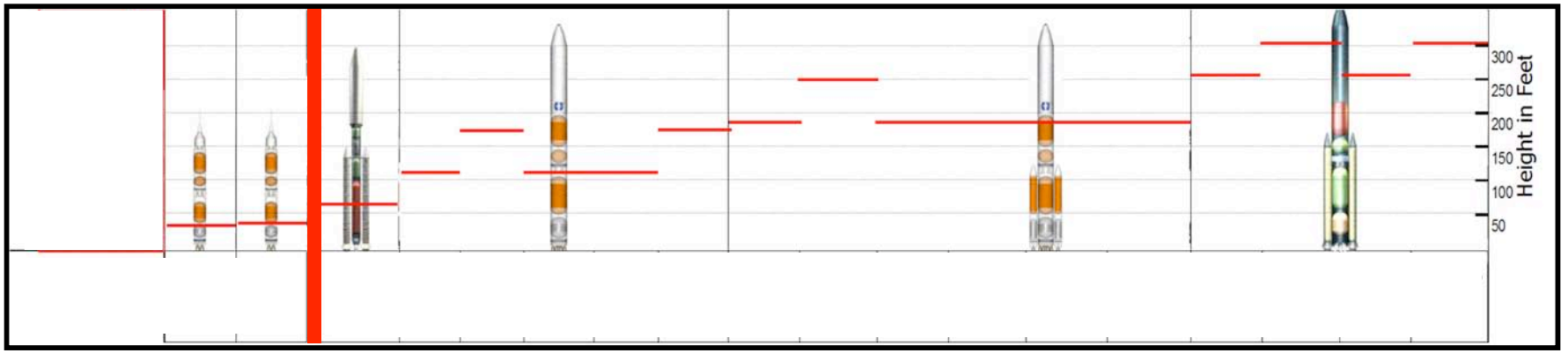


Shuttle Derived

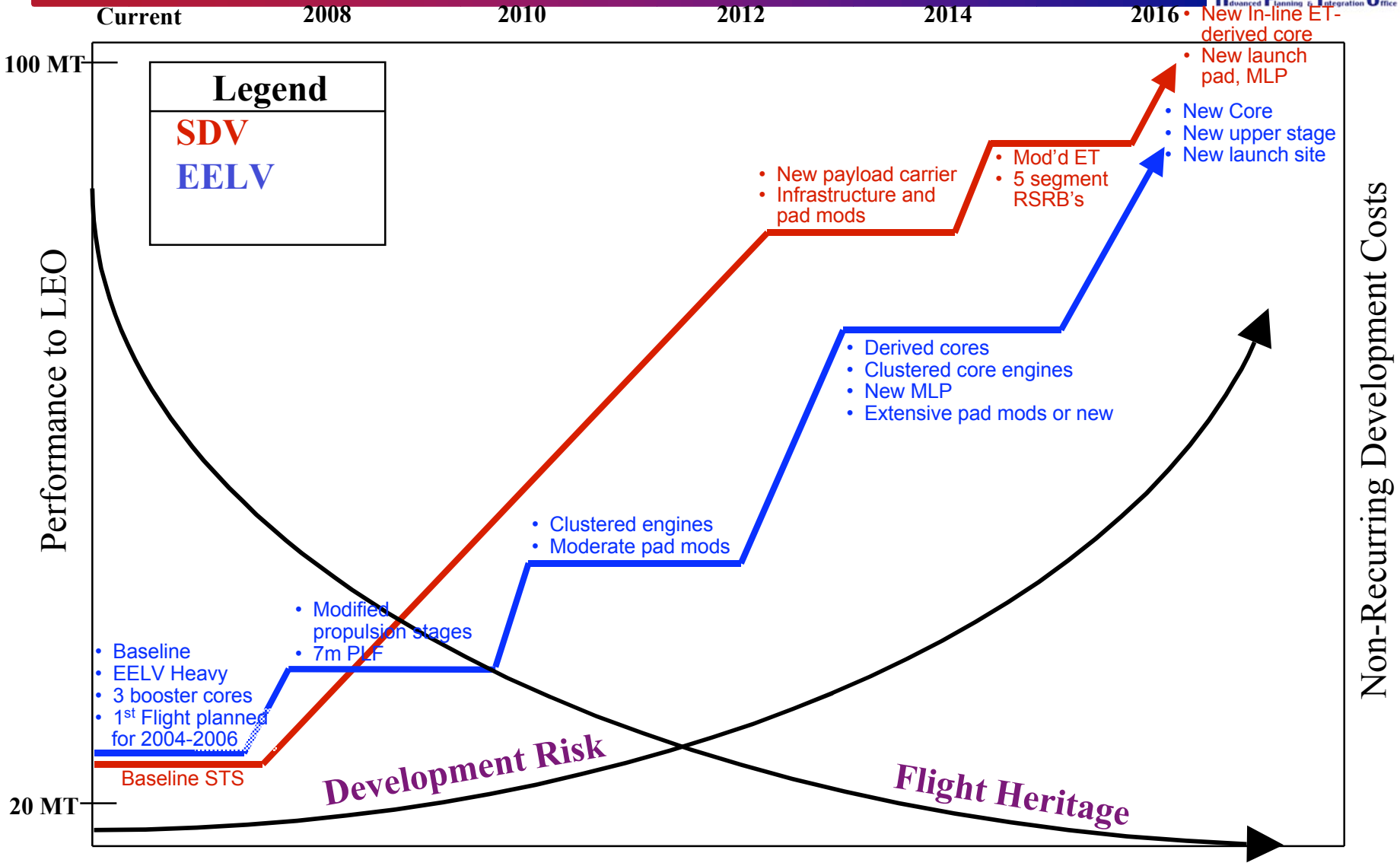


- *Evolution Alternatives*
  - *EELV Derived*
  - *Shuttle Derived*
  - *"Hybrid" Configurations*
- *35 Cargo Alternatives*
- *12 Crew Alternatives*

"Hybrid" Configurations



Future Heavy Lift Vehicle Evolution



What we have learned so far

- **Launch Vehicle Study - Integrated assessment**
  - Several paths exist to evolve from a crew to a heavy lift cargo capability
  - "Hybrid" configuration options do not offer advantages over proposed EELV and Shuttle derivatives
  - All human-rated launch system concepts assessed show the potential to meet the crew safety of 1/1,000
  - DDT&E costs for human-rating or heavy lift capabilities will require significant government investment (costs will be validated via independent assessment)
  - Cost effectiveness and reliability of launch system can be optimized by higher flight rates (multiple customers – e.g. NASA, AF, NRO, etc.)
  - Clear capability bands identified to support the Analysis of Alternatives
    - 8 - 15 mT
    - 20 - 30 mT
    - 40 - 50 mT
    - 70+ mT

Work Ahead

- Continue looking for the sensitivities within various architectures based on Launch Vehicle lift capability

No down-select of Launch Vehicle has been made

- Continue with AOA Phase 2
  - Assess Mixed Fleet LV options and other transportation options
  - Refine cost assessments for ALL scenarios
- Provide Integrated Assessment
  - Identify Agency-wide synergy
  - Assure compliance with Space Transportation Policy

Backup

Committee Membership

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Mission Directorate Coordinator

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APIO Coordinator/FACA DFO

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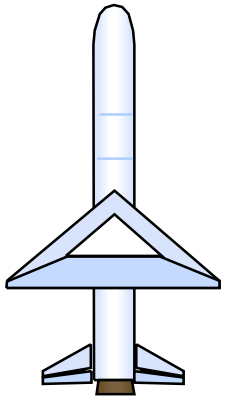
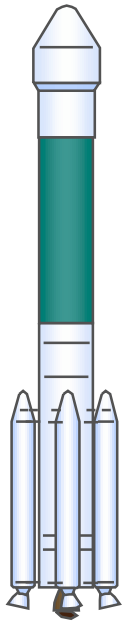
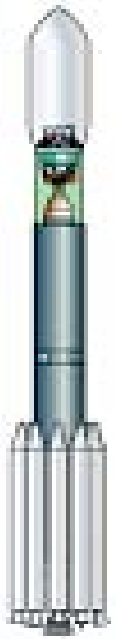
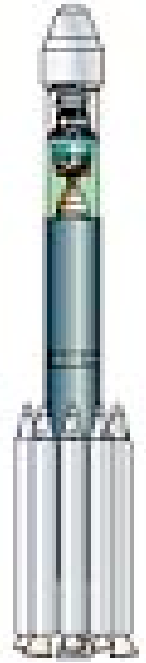
Figures of Merit

- Crew Safety and Mission Success
  - Crew Safety - Launch phase
  - Crew Safety – Abort Phase
  - Mission success – Launch Campaign
  - Mission success - Critical in-space events
- Affordability
  - Non-Recurring Cost
  - Recurring Cost
  - Cost Phasing
- Programmatic Risks
  - Technology Development risk
  - Launch Processing/throughput risk
  - Development Schedule risk
- Extensibility
  - Evolvable to Mars Mission
  - National Security Commonality
  - Commercial Opportunities

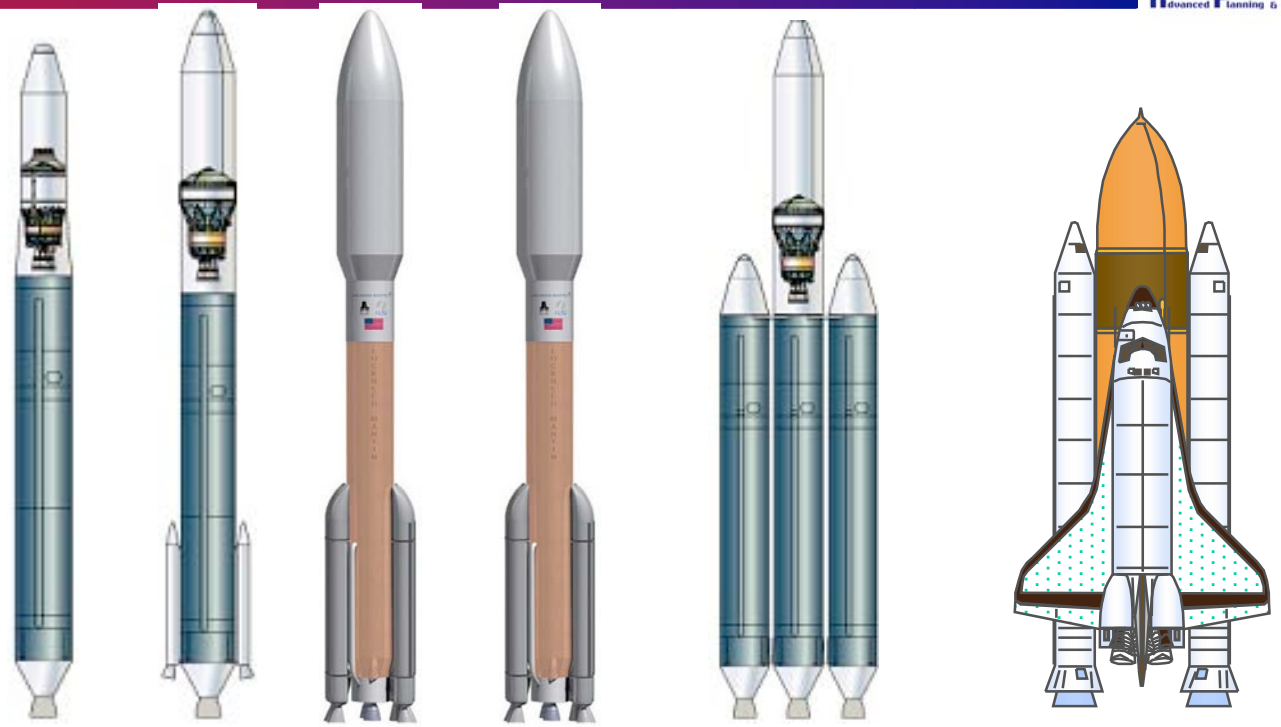
Current Small US Launch Capability



Launch Vehicle	Pegasus	Taurus	Delta II 73XX	Delta II 79XX	Delta II 79XXH
Supplier	Orbital Sciences Corp.	Orbital Sciences Corp.	Boeing	Boeing	Boeing
LEO (kg)	453	568	2,796	5,140	6,000
SSO (kg)	191	302	1,685	3,220	No WTR
ISS (kg)	350	455	2,435	4,440	5,200
GTO (kg)	N/A	N/A	1,000	1,870	2,100
High Energy C3=0	N/A	N/A	725	1,250	1,500
High Energy C3=10	N/A	N/A	600	1,000	1,300

Current Large Class US Launch Capability



Launch Vehicle	Delta IV 4040	Delta IV 4450	Atlas V 50X	Atlas V 55X	Delta IV Heavy	Space Shuttle
Launch Service	Boeing	Boeing	LM	LM	Boeing	NASA
LEO (kg)	8,600	13,100	9,540	18,000	23,165	22,600
SSO (kg)	6,300	9,600	No WTR	No WTR	21,040	N/A
ISS (kg)	7,700	11,800	8,500	17,500	23,900	16,800
GTO (kg)	3,985	6,345	3,880	8,570	12,650	2200*
High Energy C3=0	2735	4,580	2680	6330	9305	N/A
High Energy C3=10	2115	3,685	2150	5300	7810	N/A

* Assumes IUS Upper Stage

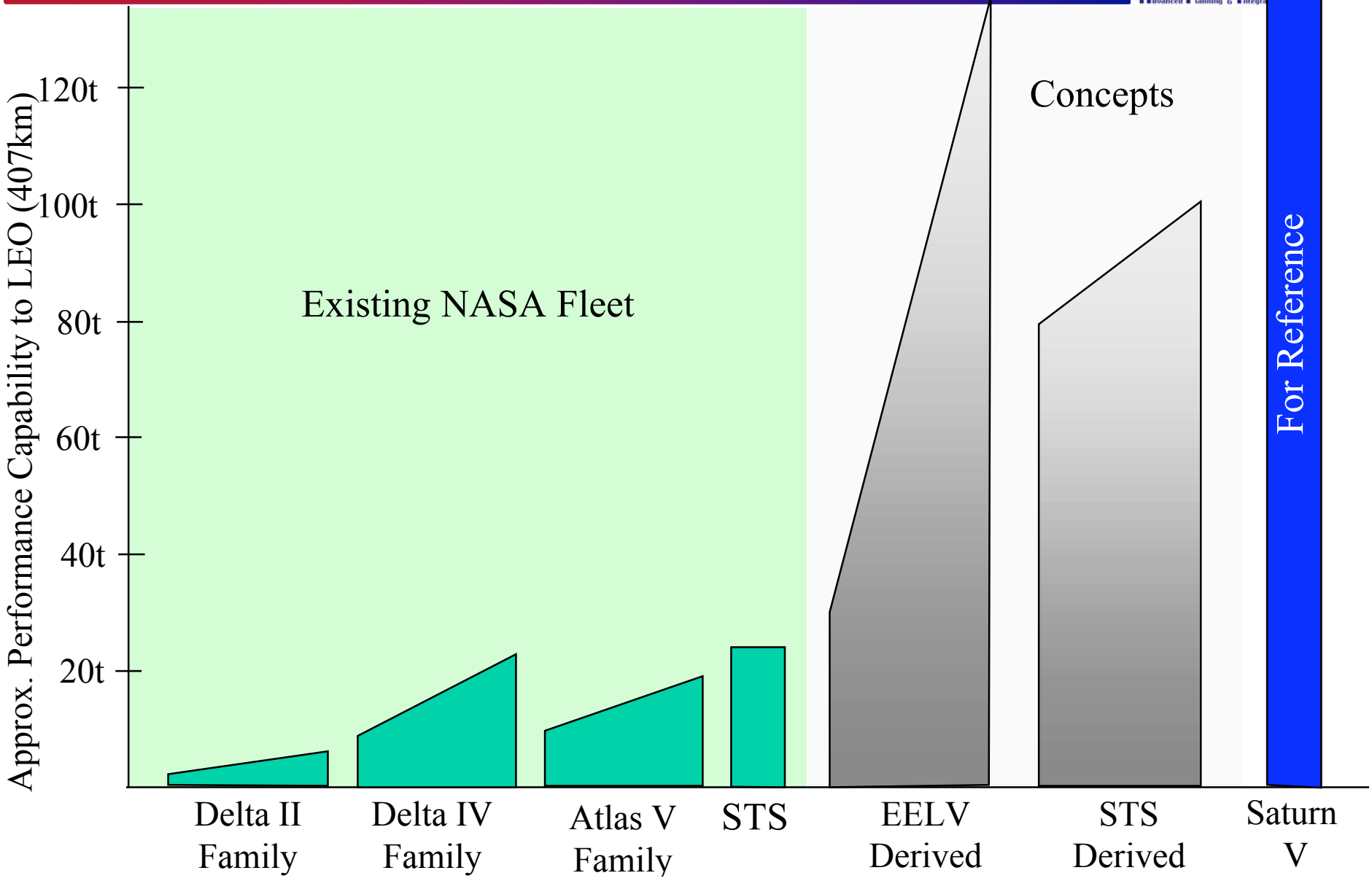
Advanced Planning

- **Support to ISS**
  - Providing definition of current launch capability to support ISS cargo requirements
  - Identifying options for supporting ISS cargo upon retirement of the Shuttle
    - Mixed fleet assessments for cargo up and down mass
    - Plan to acquire domestic services to augment partner capability

- **Support to Space Exploration**
  - Providing definition of current launch capability to support robotic, cargo and human exploration missions
    - Supported trade studies for OSP and JIMO, provide basis for CEV follow on assessments
    - Updating earlier Shuttle evolution options to address Space Exploration needs
  - Identifying potential vehicle enhancements
    - Reliability and performance
    - Considerations for compliance with human rating
    - Keeping NRO/USAF apprised of issues/trade space- potential for areas of synergy

- **Seek to integrate assured access to space strategy to meet both sets of emerging requirements along with known science needs**
  - Reviewing results from RFI, released in late-2004, soliciting US industry interests /capabilities to meet full range of NASA launch requirements

LV Performance Comparison



Launch Vehicle Family Options

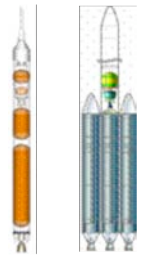
Advanced Planning & Integration Office

Path 1: Existing EELVs

Option 1a
Delta Family

Crew: Single Stick w/ HR 4RL10 US

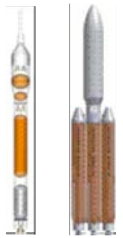
Cargo: Standard Delta IV Heavy



Option 1b
Atlas Family

Crew: Single Stick w/ HR 4RL10 US

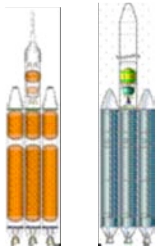
Cargo: Standard Atlas V Heavy



Option 2a
Delta Heavy

Crew: Heavy w/ HR 4RL10 US

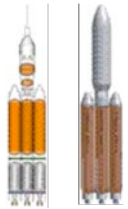
Cargo: Heavy w/ 4RL10 US



Option 2b
Atlas Heavy

Crew: Heavy w/ HR 4RL10 US

Cargo: Heavy w/ 4RL10 US

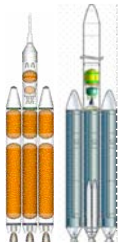


Path 2: Delta 4 Growth

Option 3
Delta Growth

Crew: Heavy w/ HR 4RL10 US

Cargo: Heavy w/ XFeed, RGen Noz, & 3RL10 US

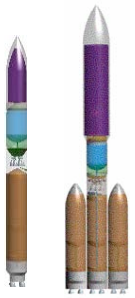


Path 3: Atlas 5 Growth

Option 4
Atlas Phase 2

Crew: 5.4m 2Eng Core, 4RL10 US, 4 Solid S/O

Cargo: Crew Core & 2 Crew S1 S/O



Option 10
Atlas Phase 3

Crew: 8.2m 5Eng Core, 4R60 US

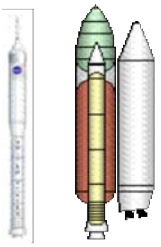
Cargo: Crew Core & 4 Crew S1 S/O

Path 4: Shuttle Derived

Option 5
SRB Stick / Sidemount

Crew: 4 Seg SRB w/ HR J2S US

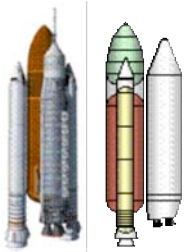
Cargo: 3 Eng SD Side Mount w/ 2 4Seg SRB



Option 8
Sidemount/Sidemount

Crew: 3 Eng SD SM Crew & Cargo w/ 2 5Seg SRB

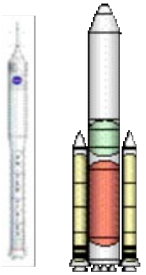
Cargo: Cargo Only Variant of Crew LV



Option 6
SRB Stick/Inline

Crew: 4 Seg SRB w/ HR J2S US

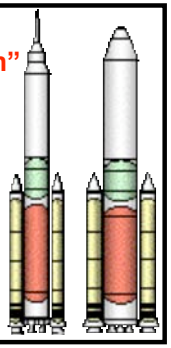
Cargo: 3 Eng SD In-Line w/ 2 4Seg SRB (No US)



Option 9
"2 Launch Solution"

Crew: 4 Eng SD IL Crew & Cargo w/ 2 5Seg SRB

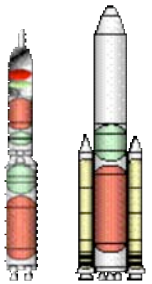
Cargo: Cargo Only Variant of Crew LV



Option 7
ET Derived/Inline

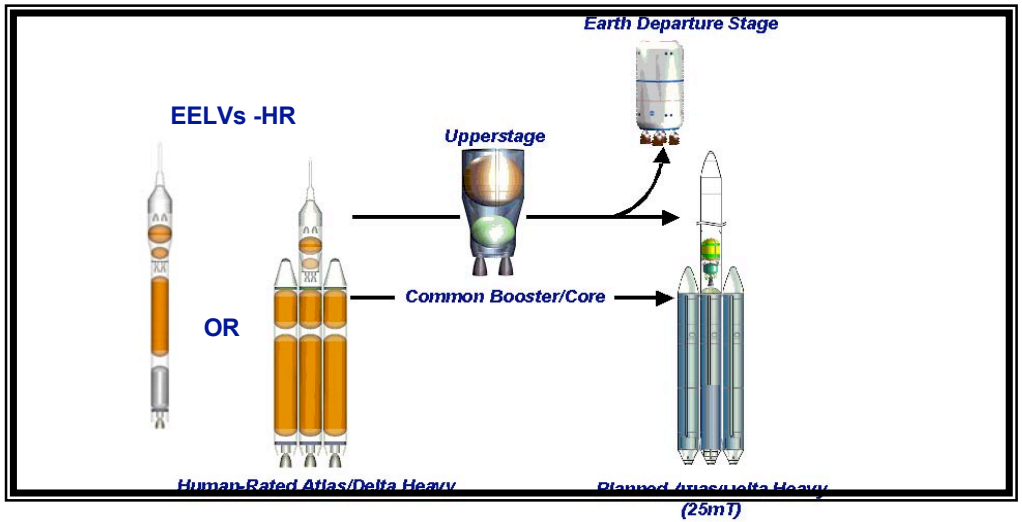
Crew: 4 Eng ET-Based w/ J2S US

Cargo: 4 Eng ET-Based SD In-Line w/ 2 4Seg SRB (No US)



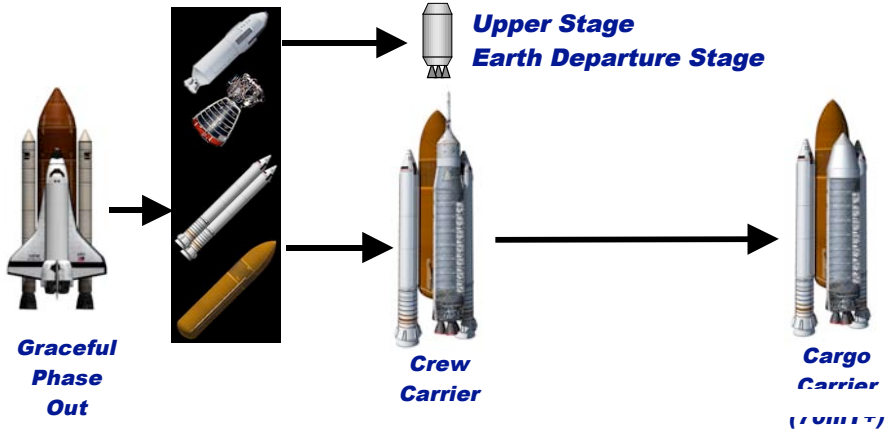
Evolutionary Paths

Commercial/DoD EELV Paths

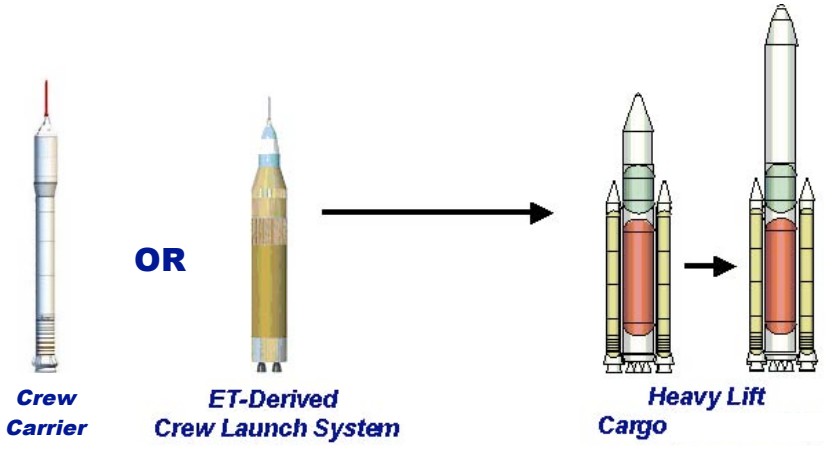


Shuttle-Derived Paths

Shuttle-Derived Sidemount Carrier



Shuttle-Derived In-Line Carrier

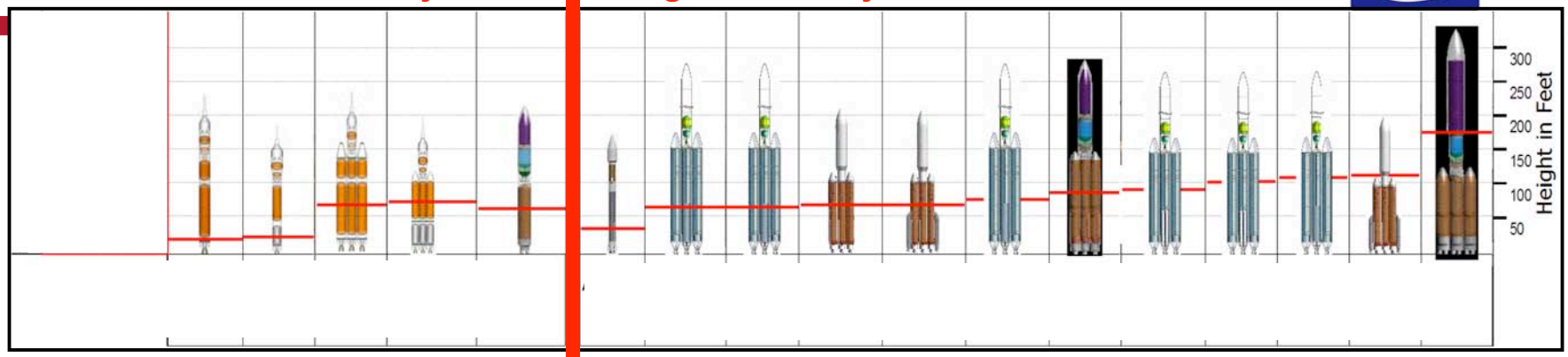


Reduced Set of Launch System Alternatives

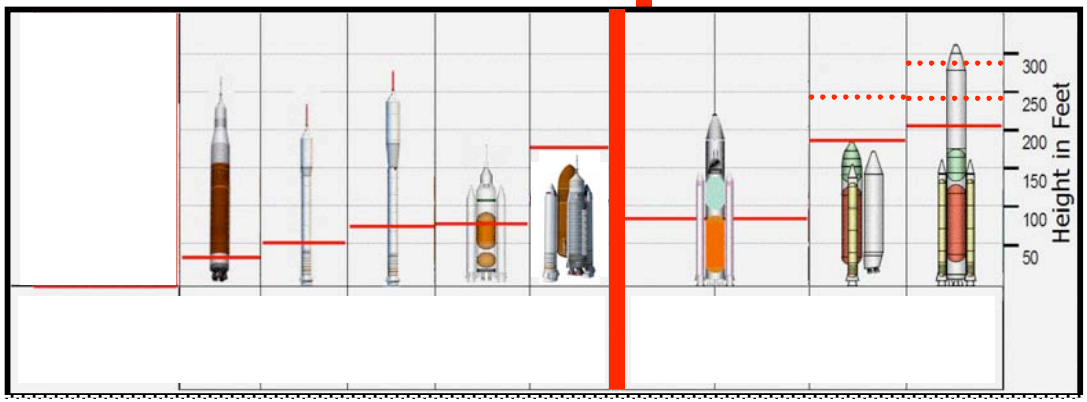
Crew Launch Systems

Cargo Launch Systems

EELV-Derived

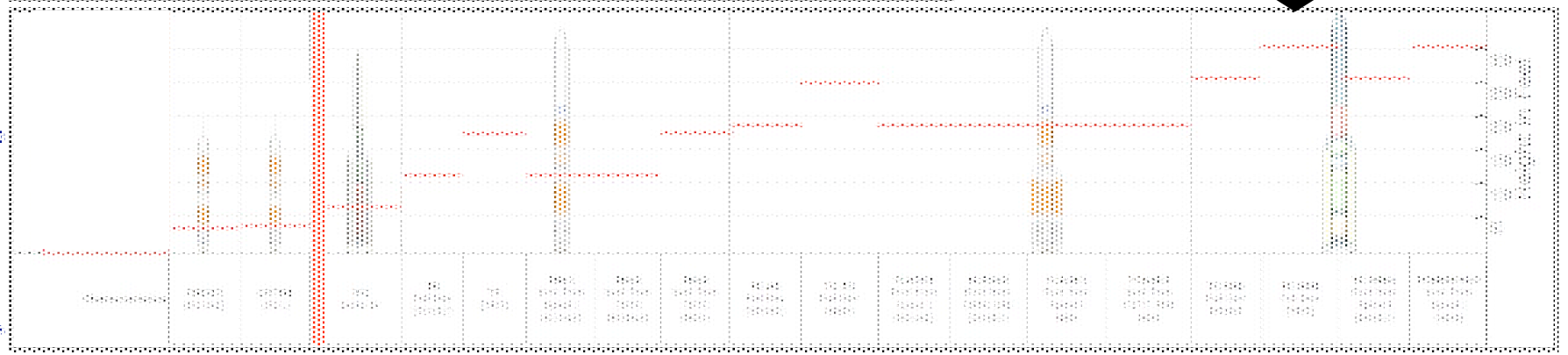


Shuttle-Derived

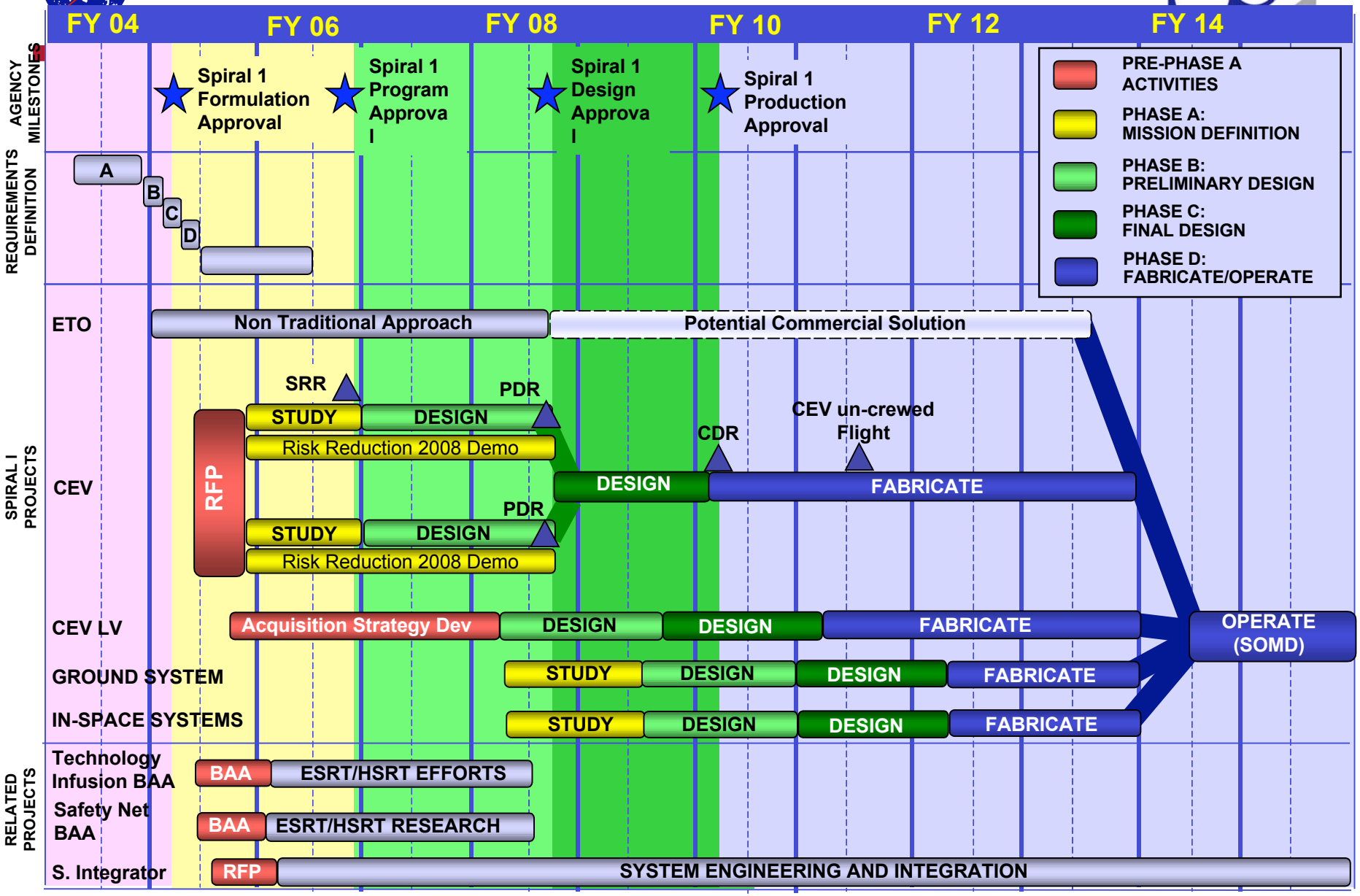


- *"Hybrid" Configurations have no clear advantage over EELV and Shuttle derived alternatives*
- *19 Cargo*
- *10 Crew*

"Hybrid" Configurations



Spiral I Program



ETO: Earth-to-Orbit CEV: Crew Exploration Vehicle LV: Launch Vehcile BAA: Broad Area Announcement SOMD: Space Ops Mission Directorate

Launch System Study – Background

- **47 Launch systems configurations were studied**
  - EELV Derived
  - Shuttle Derived
  - "Hybrid" Configurations

- **Key In-House Launch System Study Findings**
  - **Several paths exist to evolve from a crew to a heavy lift cargo capability**
  - **"Hybrid" options do not offer enough benefit to justify the cost/risk**
  - **Launch systems can be clearly categorized into 4 payload classes:**
    - **8 - 15 mT**
    - **20 - 30 mT**
    - **40 - 50 mT**
    - **70+ mT**

} ***Several Current/Planned Systems Exist***

CEV Launcher Options

8 – 15 mT

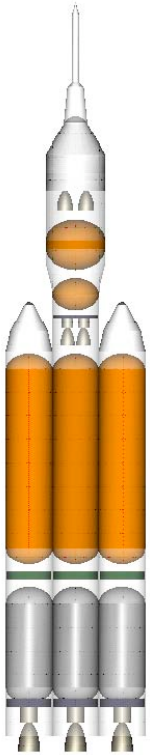
Atlas 504 HR

Delta IV M HR

20 – 30mT

ILC RSRB4

Atlas Phase 2

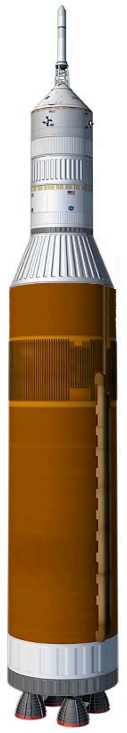


Atlas V Heavy MR

Delta IV Heavy MR

30+ mT

Atlas Phase 3



ET-Derived In-Line

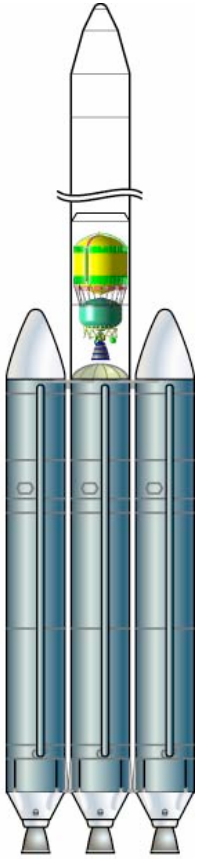
Shuttle-Derived Sidemount Crew

Cargo Launcher Options

Advanced Planning & Integration Office

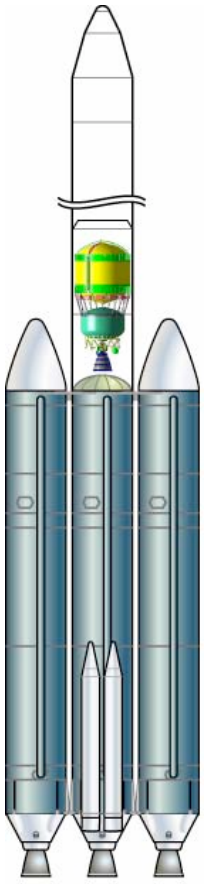
25 mT

Atlas V Heavy



Delta IV-H

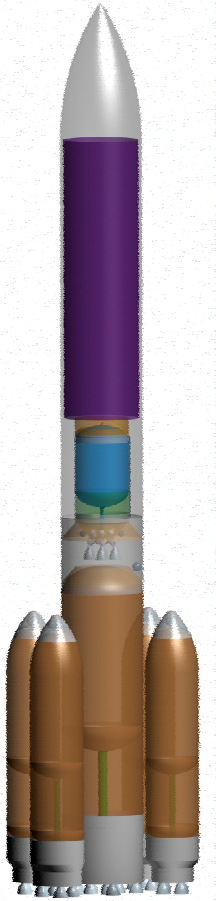
40 mT



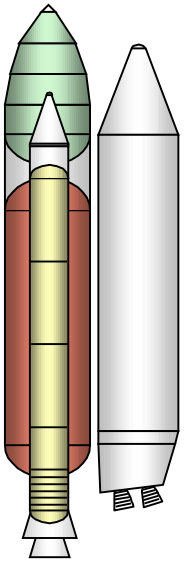
Delta IV-H Upgrade

70 mT +

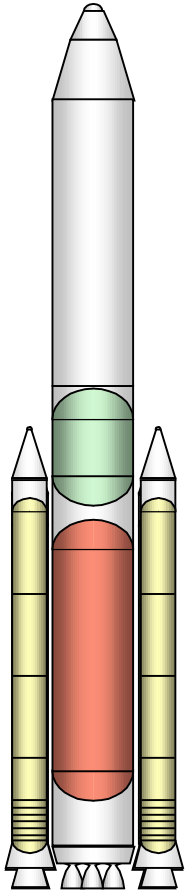
Atlas V Phase 2



Atlas V Phase 3



Shuttle-Derived (Side-Mount)



Shuttle-Derived (In-Line)